Radiation protection

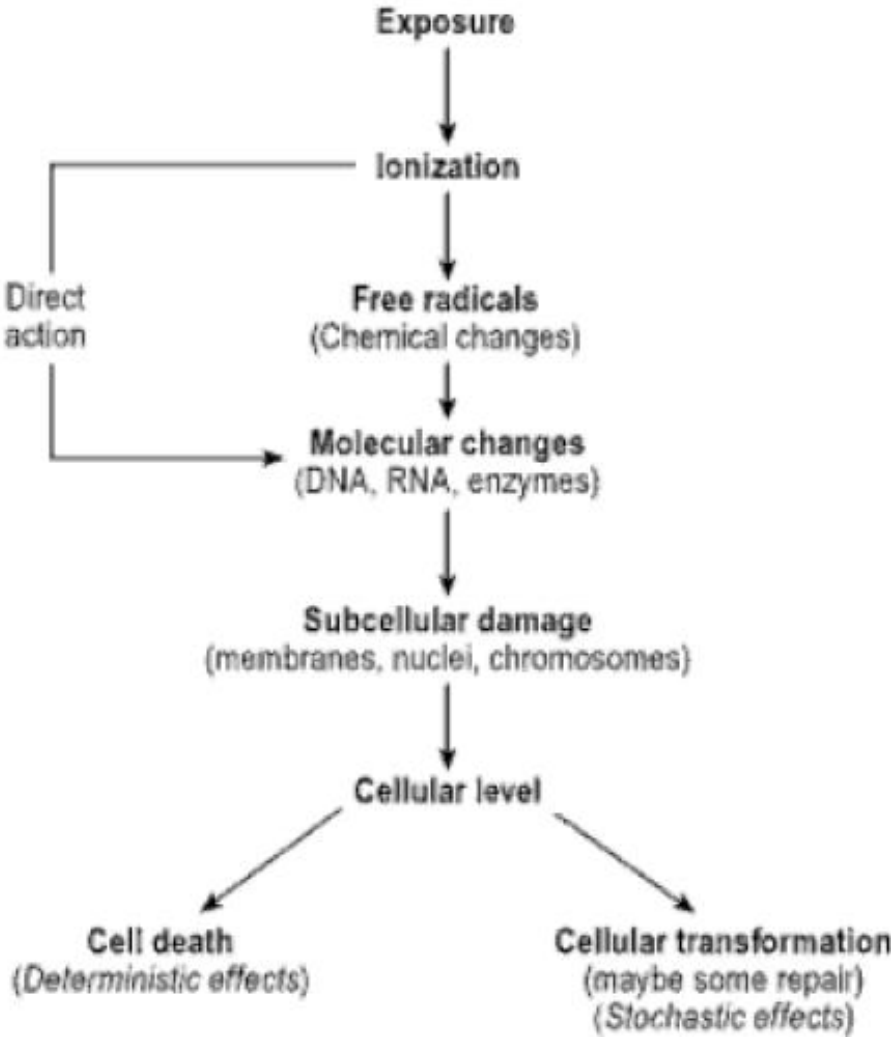
Interaction of ionizing radiation with tissues

- Whenever radiation is absorbed
  - chemical changes are produced immediately,
  - molecular damage follows in seconds to minutes.
  - During hours to decades, the biological damage becomes evident
- Effects according to type of radiation
  - The total range of β particles is few mms → easily absorbed by a shield of a few millimeters of perspex or by thin sheets of metal
  - X- and gamma radiations do not have a maximum depth of penetration associated with them, but they simply undergo progressive attenuation (intensity never falls to zero).

- The chemical damage to tissues occurs in two basic ways:
  - by producing lesions in solute molecules directly (e.g. by rupturing a covalent bond)
  - by an indirect action of the free radicals
    - Free radicals are produced during the ionization of water

    $H_20 + \text{radiation} \rightarrow H_2O^+ + e^-$

    $H_2O^+ \rightarrow H^+ + OH.$
    - more common (living tissue has about 70-90% water)
    - The hydroxyl free radical OH is a highly reactive and powerful oxidizing agent that produces chemical modifications in solute organic molecules.
    - These interactions
      - occur in microseconds after exposure
      - are one way in which a sequence of complex chemical events can be started



Definitions

- **Linear energy transfer (LET):**
  - the sum of the energy deposited in tissue per unit path length.
  - X- and gamma rays are indirectly ionizing radiations, and the produced Electrons cause ionization over a distance that is relatively large (have a low ionization density = low LET)
  - alpha particles (helium nucleus with 2 protons & 2 neutrons) are heavier. For the same initial energy as an electron, an alpha particle travels a much shorter distance (high-LET =ionizing events are more closely spaced)
  - DNA Damage caused by high-LET radiations is more likely to be non-repairable
- **Relative biological effectiveness (RBE):**
  - ratio of absorbed doses required to induce the same biological end point for two radiation types.
  - expressed in terms of a comparison with a reference beam of X-rays.
  - = 20 or greater for alpha particles (i.e. produce the same biological end point as X-rays with 5% or less absorbed dose).

RADIATION DOSES AND UNITS

- There are measurable quantities related to radiation energy transferred (kerma) or absorbed (absorbed dose) ***see before***
- Yet, biological factors depend on radiation type and the relative radiosensitivities of the different organs Two further dosimetry quantities were introduced

Equivalent dose:

- quantity used in radiation protection i.e. for relatively low levels of dose.
- = absorbed dose x radiation weighting factor (W_R)**.**
- W_R:
  - depends on radiation type
  - =1 for X- and gamma rays, electrons and beta particles.
  - = 20 For alpha particles
  - for protons and neutrons = 5, 10 or 20 depending on radiation energy.
- unit of equivalent dose is sievert (Sv)
- Radiodiagnosis is concerned only about X and gamma rays → Absorbed dose and equivalent dose are numerically equal.

Effective dose:

- Radiation protection dosimetry quantity that incorporates factors to account for the variable radiosensitivities of organs and tissues in the body.
- it also has the unit: sievert.
- See later for more details

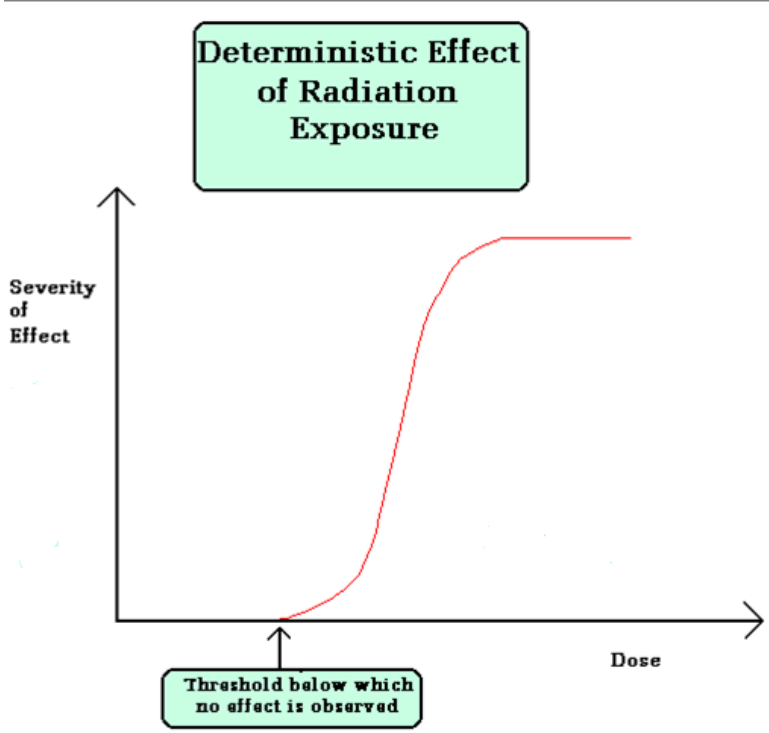
CLASSIFICATIONS OF EFFECTS OF RADIATION

First classification:

- **Genetic or hereditary effects**: occur in the descendants of those individuals as a result of lesions in the germinal cells.
- **Somatic effects:** occur in the individual exposed

Second classification:

- **1- Deterministic effects:**
  - Definition: effects that Have a Threshold dose:
    - Threshold dose is the dose below which the effect will not occur
    - Value of threshold vary to a small extent from individual to individual
    - Once the threshold dose is exceeded → the likelihood of the effect occurring increases rapidly with dose up to a level at which the effect will invariably occur.
    - Severity increase with dose
    - May or may not have a cumulative effect:
      - The damage to the eye (Cataract) is cumulative→ Attention has to be paid to the lifetime dose for those working in radiation-intense areas (e.g. interventional radiology).
      - However, most deterministic effects have repair mechanisms → rate at which the dose is delivered influences the threshold dose.
        - » E.g. the threshold dose for skin erythema =2-5Gy ,but lf somebody received 20mGy/ week over many years , effect will not occur (although accumulated dose at 5 years = 5 Gy)



Some important threshold doses

Symptoms Dose	Threshold (Gy)
Erythema	2-5
Irreversible skin damage	20-40
Hair loss	2-5
Sterility	2-3
Cataract	5
Fetal abnormality	0.1-0.5

Typical absorbed dose in diagnostic radiology

examination	Dose (mGy)
PA chest	0.15
AP abdomen	5
Lat. Lumber spine	12
CT scan	10-30
Fluoroscopy skin dose rate	5-50 mGy/m

Note that:

•Threshold doses are of little significance in diagnostic radiology

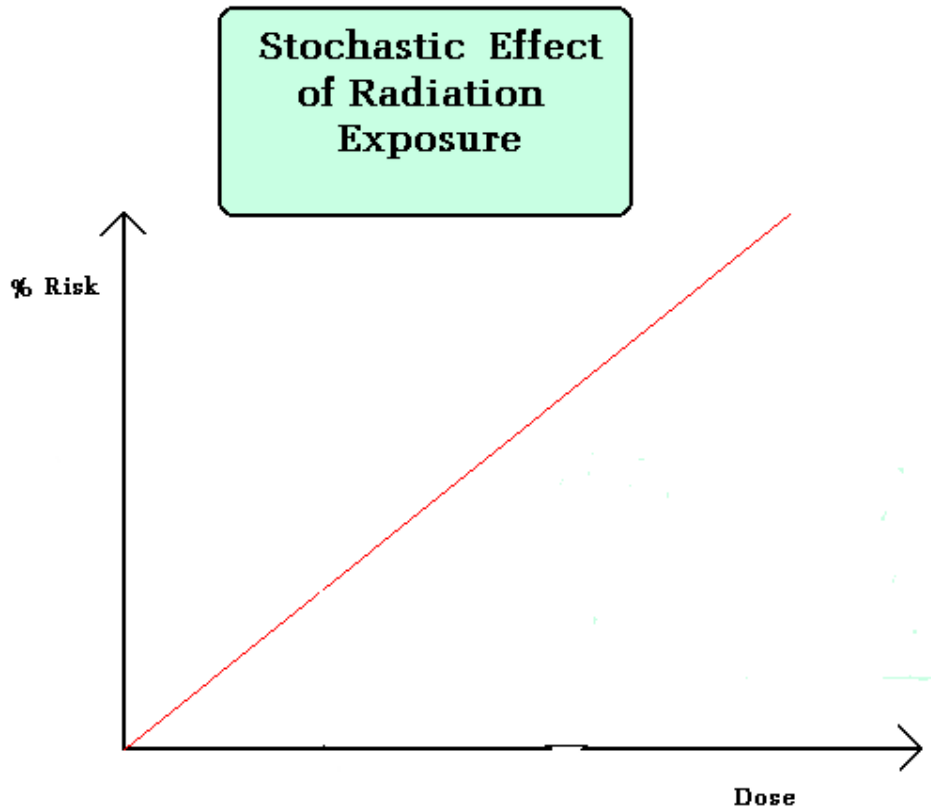
•Cumulative nature of cataract effect increase its possibility in patients having several CT scans over their lifetime

•Some complex interventional procedures associated with long screening times (up to 60 m) may increase the risk of occurrence of skin erythema and hair loss (Fluoroscopy skin dose rate may reach 50 mGy/m)

N.B: Fetal deterministic effects:

- Range from birth abnormalities (down syndrome) to spontaneous abortion
- Greatest risk is at 3rd to 8th weeks

- **2- Stochastic effects:**
  - Effects that arise by chance
  - Has No threshold
  - Risk of occurrence increase linearly with dose (linear non threshold theory)
  - Severity of effect dose not increase with dose (all or non)



There are Two types of stochastic effects:

- **A- carcinogenisis:**
- The table shows organ-specific risk factors for development of **fatal** cancers (not incidence of cancers as whole)

e.g. thyroid risk factor is relatively ↓ (despite ↑ induction probability) because mortality is low.

- Overall, for a uniform whole body irradiation →the risk of fatal cancer is 5% per Sv (or 1 in 20000 per mSv)

i.e. irradiating a population of 20000 people to a uniform, whole body dose of 1 mSv would result in one excess cancer death in that population.

- latency period between irradiation and clinical manifestation of cancer varies:
  - Leukaemias (due to irradiation of the red bone marrow) have a latency period of 7-10 years following irradiation.
  - Solid tumours have latency of 40 years or more.
- Consequences of long latency period:
  - Estimation of risk following the irradiation of a population is difficult to assess.
  - The risk to the younger population with a long life expectancy is greater than that to the older population (risk to children is more than double the value averaged over the whole population).

Organ or tissue	Risk factor (% per Sv)
Gonads	–
Stomach	1.10
Colon	0.85
Lung	0.85
Red bone marrow	0.50
Bladder	0.30
Oesophagus	0.30
Breast	0.20
Liver	0.15
Thyroid	0.08
Ovaries	0.10
Bone surface	0.05
Skin	0.02
Remainder	0.50
Total	5.0

N.B. Risk for developing fatal childhood cancer:

- 3% per Gy (1 in 33000 per mGy)
- Risk is less in first few weeks of pregnancy
- General Incidence of fatal childhood cancer = 1 in 1800
  → i.e. 17mGy is required to double the natural risk (= dose to the CT pelvis of the mother)

- **B- Genetic effects:**
  - It is difficult to assess the genetic risk in humans.
  - Studies proved that there are no any excess of genetic disorders for children of irradiated parents compared to children of non-irradiated parents.
  - However, in view of the paucity of data, a safety margin is included in all risk estimates. The risk of hereditary ill health in future generations is estimated to be 1 in 70000 for an exposure of 1 mGy to the gonads.
  - This is the risk averaged over the whole population. For the reproductive population the risk is obviously greater and is estimated as 1 in 40 000.

Effective dose

- **Tissue weighting factor (W_T)**: factor that indicate carcinogenic risk of a certain tissue
  - *W_T of high risk tissues = 0.12 ,*
    of moderate risk tissues = 0.05
    of low risk tissues = 0.01
    Gonads W_T = 0.2 (due to risk of genetic effects)
- **Weighted organ dose** = *tissue equivalent dose (H_T) X tissue weighted factor (W_T)*
- **Effective (whole body) dose** = *The sum of* Weighted organ doses= $\Sigma W_T . H_T$
- Effective dose is calculated to give effective risk of the examination (independent on uniformity of exposure of whole body)
- Used to compare the risk from one procedure to the other.
- It has the same unit as equivalent dose, i.e. Sv

Organ or tissue	Risk factor (% per Sv)	Weighting factor (w_T)
Gonads	–	0.20
Stomach	1.10	0.12
Colon	0.85	0.12
Lung	0.85	0.12
Red bone marrow	0.50	0.12
Bladder	0.30	0.05
Oesophagus	0.30	0.05
Breast	0.20	0.05
Liver	0.15	0.05
Thyroid	0.08	0.05
Ovaries	0.10	–
Bone surface	0.05	0.01
Skin	0.02	0.01
Remainder	0.50	0.05
Total	5.0	1

Example: effective dose for AP thoracic spine

Organ	Organ equivalent dose (per mSv exam equivalent dose)	W_T	Weighted organ dose /mSv (W_T . H_T / mSv)
Gonads	0.001	0.2	↓0.001
Stomach	0.34	0.12	0.041
Colon	0.001	0.12	↓0.001
Lung	0.56	0.12	0.067
Red bone marrow	0.12	0.12	0.014
Bladder	0.0004	0.05	↓0.001
Eosophegus	0.4	0.05	0.02
Breast	0.56	0.05	0.028
Liver	0.38	0.05	0.019
Thyroid	0.63	0.05	0.032
Bone surface	0.26	0.01	0.003
Skin	0.15	0.01	0.002
Remainder*	0.15	0.05	0.008
Effective dose per mSv exam equivalent dose	-		0.234

***Remainder tissues include adrenals , brain , kidney , muscle , small intestine , pancreas , spleen , thymus , uterus (tissues which show some evidence of cancer induction but data is insufficient to provide specific risk factor), they are collectively given $W_T = 0.5$**

Notes:

- After calculating exam effective dose , risk of fatal cancers caused by this examination can be calculated (1 in 20000 per mSv)
- Examination with effective dose of = 0.23 mSv will cause the same risk of receiving uniform whole body absorbed dose of 0.23 mGy

Population dose

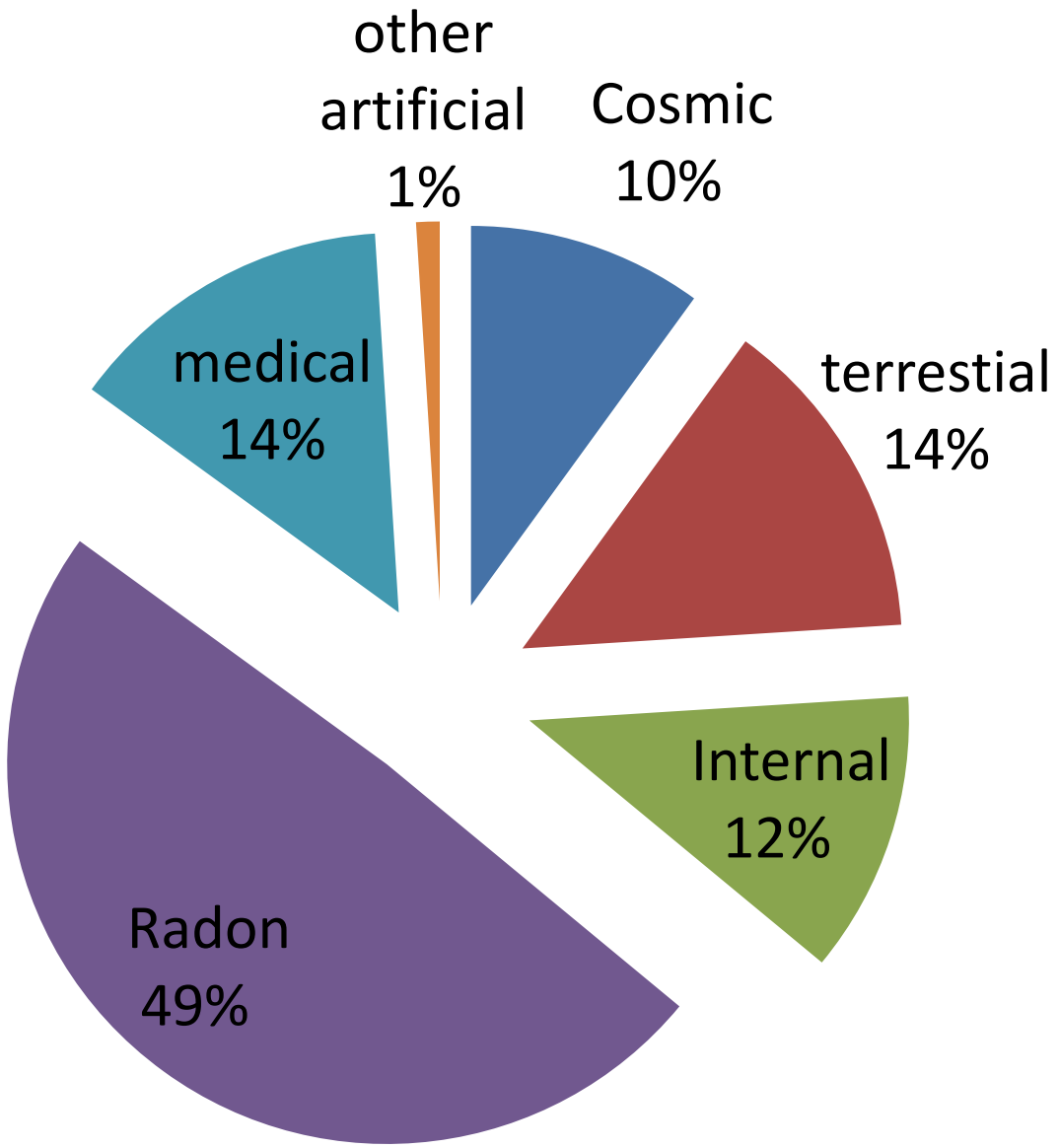
Natural sources of irradiation to population:

- Cosmic radiation:
  - Generated in the space (e.g. sun)
  - Mixture of particulate radiation and broad spectrum X & γ rays
  - Most of it is attenuated by the atmosphere
  - At sea level amount of cosmic radiation = 320 µSv/year (increase with altitude)
- Terrestrial gamma rays:
  - Emitted from radioactive materials in the earth's crust.
  - About 350 µSv/year
  - the amount depending on location and on the materials used in the construction of the buildings

- Internal sources of radiation:
  - 27O µSv/year.
  - Example: naturally occurring radioisotope potassium-40
    - Potassium is an essential part of our diet,
    - It contributes about 60% of our internal radiation exposure.
  - There are other natural radionuclides in the food
  - the extent to which we are exposed depends on the diet
- Radon:
  - produced in the decay chain of uranium.
  - Like all elements with atomic numbers greater than 82:
    - it is radioactive
    - its decay is associated with the emission of alpha particles.
  - It is an inert gas and may permeate through the ground and into buildings.
  - It represents
    - the largest source of radiation to which we are exposed (an average of 1.3 mSv/ year in the UK)
    - The most Variable (doses in individual houses being as high as 50 mSv /year due to the geology of the underlying ground)
- From all natural sources, the average dose to the UK population is 2.2 mSv /year, rising to about 7mSv in Cornwall due to radon.

Artificial sources of irradiation to population

- Include:
  - Fallout from nuclear weapons tests (4 μ Sv),
  - Miscellaneous sources such as those used in smoke detectors (0.1 μ Sv),
  - Nuclear discharges (0.3 μ Sv)
  - Occupational exposure (6 μ Sv).
  - Diagnostic medical radiation procedures:
    - The largest artificial source
    - Contributes about 370 μSv. → diagnostic radiology in the UK, with a population of nearly 60 million, results in over 1000 cancer deaths each year (1 cancer death in 20000 per mSv), yet , This is an overestimate, because the irradiated population is usually the higher age group.
- we receive an average of 0.4 mSv from all artificial sources of radiation.


other artificial 1%
Cosmic 10%
medical 14%
terrestial 14%
Internal 12%
Radon 49%

PRINCIPLES OF RADIATION PROTECTION

- proposed by the **International Commission on Radiological Protection (ICRP)** which introduced three basic principles:

1) Justification:

- Definition:
  - Ionizing radiations should not be used unless it can be demonstrated that the benefit exceeds the risk to those who are liable to be exposed.
  - Benefit may be to Society e.g. benefits those working because they have employment)
  - On the risk side:
    - Radiation dose received
    - Accidents and unexpected or unusual occurrences.
  - Example: High doses of radiation give symptomatic relief for ankylosing spondylitis patients , but risks of radiation, makes the benefit outweighed by the risk.

- Justification in diagnostic radiology:
  - The risks are much less.
  - Justification must consider
    - The likelihood of the examination influencing the management of the patient
    - The alternatives (e.g. U/S)
    - Dose (Risk is proportional to dose)
    - Age (risk is significantly greater for children than for adults)
    - The possibility of pregnancy for examinations of the pelvis or lower abdomen.
    - It is easier to justify the use of X-rays for the patient who is seriously ill and for whom an accurate diagnosis could significantly affect clinical outcome than it is for a relatively minor condition.
    - Great care is needed for the justification of an exposure of a healthy individual (e.g. screening mammogram, volunteer in a medical research)
    - The risk to the operator must also be considered even when benefit to the patient may be significant (e.g. biopsy using real-time CT →high finger doses)

2) Optimization

- Definition:
  - The dose should be :As low as reasonably achievable (the ALARA principle)
  - OR as low as reasonably practicable (ALARP) is the UK legal phrase-ology.
- Optimization is incorporated into:
  - The design of equipment: e.g. the control of X-ray output during fluoroscopy.
  - The selection of technique to produce diagnostic images at the lowest possible dose (e.g. selection of KV).
  - Operator technique (e.g. use of the minimum screening times in fluoroscopy)
  - Quality assurance programmes to ensure equipment performance.

3) Dose limitation:

- Definition:
  - Doses in excess of which exam are not to be justified no matter how great the benefit (above which risk is not tolerable).
- Dose limits apply to those who are employed to work with radiation and to members of the public who are liable to be exposed to radiation as a result of a work activity
- The limits are different because the person working with radiation receive benefit (employment) whereas the member of the public does not.
- **Dose limits do not apply to patients; the control of patient dose is based solely on the principles of justification and optimization.**
- The dose limits include limits on effective dose to restrict the risk of stochastic effects.
  - In proposing dose limits, the ICRP took account of the latency period of radiation risks (Risk increases with time and reaches a maximum value 20 years after the period of employment).

UK legislation

Health and safety at work act 1974

Health and safety commission advisory (HSC)

Health and safety executive (HSE)
- Have the power of inspection and persecution

Ionizing radiation (medical exposure) regulation IRMER (previously POPUMET)
- Concerned about patient protection
- Enforcing authority is healthcare commission

Ionizing radiation regulation 1999 (IRR 99)
- Take into account principles of ICRP
- Not concerned with patient protection (other than requirements regarding equipment for medical exposure)

Approved code of practice (ACOP)
- Means of compliance with IRR 99 that HSE would consider sufficient
- Not legal requirement (employer may demonstrate alternative methods to fulfill requirements)

Guidance representing good practice
- Lesser state than ACOP
- Failure to comply is less likely to be used as evidence of breach of regulations

THE IONISING RADIATIONS REGULATIONS 1999 (IRR 99)

1- General requirements from the employer:

- Notification
  - The employer has to notify the HSE of the intention to use ionizing radiation for the first time, including details of where the work is to be carried out and the type of work.
- Radiation protection adviser
  - The radiation employer is required to consult; a radiation protection adviser (RPA) on compliance with the regulations.
  - The RPA :
    - Must satisfy the HSE‘s requirements for competence
    - Must have experience of the employer’s business.
    - Almost invariably a medical physicist (combine radiation protection duties with medical physics)
    - May be an employee of the organization or an external consultant.

- Prior risk assessment
  - Required before any new activity involving ionizing radiation (e.g. installation of new X-ray equipment ,introduction of a new radiopharmaceutical)
  - Assessment is carried out by the RPA
  - Include risks to staff, public and patients
  - Should consider contingency plans for situations in which things may go wrong , for example:
    - X-rays are emitted outside the operator‘s control →turn the set off and not to use it again until a qualified person has corrected the fault.
    - Radioactive sources spillage
  - Contingency plans should be written into the local rules

2- annual Dose limits:

(ICRP)

	Employees (mSv)	Public (mSv)
Effective dose	20	1
Equivalent dose		
Lens of the eye	150	15
Skin, hands, forearms, feet, ankles	500	50
Abdomen of woman of reproductive capacity	13[a]	–
Fetus of pregnant employee	1[b]	–

[a]In any consecutive 3-month period.
[b]Over declared term of pregnancy.

- Effective Dose (=whole body dose) limit is Concerned with stochastic effects
- The equivalent dose limits ensure that individual doses are kept below the dose thresholds for deterministic effects, e.g.:
  - The dose limit for the skin (the dose averaged over an area of 1 cm^2)
  - Annual limit to the eye lens = 150 mSv, i.e. person who received the dose limit annually would exceed the threshold after 35 years (threshold dose for cataracts =5 Sv).
- The dose limits for employees are for those aged 18 or above, There are additional limits (three-tenths of the mentioned limits) for employees between the ages of 16 and 18.
- Distinction is made between employees who work with ionizing radiations (i.e. who enter controlled or supervised areas) and those who do not.
- It is normal practice to consider that the public dose limit applies to second type of staff.

Dose limits Pregnant staff:

- Fetal dose limit is set that is equal to the limit for a member of the public.
- The limit applies over the declared term of the pregnancy (from the date that the employee informs her employer in writing that she is pregnant).
- For diagnostic X-rays, it can be assumed that the fetal dose is no greater than 50% of the dose on the surface of the abdomen, i.e. of the dose recorded on the dose monitor.
- For higher-energy radiations, including those used for radionuclide imaging, it is assumed that the fetal dose is equal to the dose monitor reading.
- There is an additional dose limit for female staff with reproductive capacity:
  - Average dose to the abdomen must be less than 13mSv over any consecutive 3-month period.
  - Ensure that she is not liable to receive a major part of the annual dose limit over a short time period that might be coincident with interval between conception and the confirmation of pregnancy)

Dose limits for Comforters and carers:

- Sometimes a person who is not working with radiation might incur a radiation dose in excess of the public dose limit
  - E.g. parents of children treated with 10 GBq of iodine-131 meta-iodobenzylguanidine for neuroectodermal tumours ,delivering doses of 1 or 2Gy.
  - child should remain for few weeks (iodine-131 t½= 8 days) in a special facility to ensure the containment of contamination
  - The lRR99 permits the dose limit to be relaxed for comforters and carers who do not benefit from the work activity & who are willingly exposed to doses in excess of the limit.
- The employer is required to:
  - Set a dose constraint for these situations (e.g. 5mSv)
  - Explain to the person the doses and risks involved,
  - Provide guidance on precautions to be taken to ensure that the dose constraint is not exceeded.
- The relaxation of the dose limit for comforters and carers:
  - Cannot be applied to employees.
  - Doesn't apply to the diagnostic use of X-rays (A parent holding his child in position while an X-ray is taken is not a comforter as parent dose is a tiny fraction of public dose limit)

3- designation of areas and control of working practices:

a) Designation of radiation areas:

Controlled area:

- Any area in which:
  - A person working in that area is likely to receive › 3/10 of any dose limit
  - There is requirement to follow special working procedures in order to restrict exposure
  - Dose rate could exceed 7.5 µSv/h averaged over the working day
- Examples:
  - X-Ray room
  - Radionuclide injection room
- Requirements:
  - Sufficient room walls shielding (→adjacent rooms are not required to be controlled areas)
  - Access is restricted to staff (who are required to be present) and patients
    - person operating X-ray may control room access
    - Door lock in areas requiring radioactive material use (no switching off)
    - Prior risk assessment determine the appropriate form of access control
  - Clearly marked with warning sign
- Controlled area in case of mobile X-ray equipment:
  - Can not design the whole ward as controlled area
  - Controlled area is the area within 2 m of the x-ray tube and the patient
  - Radiographer must ensure that no staff is closer to patient unless wearing a lead apron

Supervised area:

- Definition:
  - Area in which there is a possibility of exposure of staff or public , but the doses are insufficient to require designation as controlled area
- Room is supervised area if:
  - It is necessary to keep the exposure conditions under review to determine whether designation as controlled area will be required
  - A person inside could exceed dose limit of a member of public (1 mSv/year)
- Example: radionuclide waiting room

b) Local rules (written working procedures):

- Definition:
  - Written instructions for people working in controlled and supervised areas
- Responsibility of employer , Set by RPS , enforced by HSE
- Includes:
  - Description of controlled and supervised areas
  - Identification of:
    - Names of RPA & RPS
    - Responsibility for radiation protection
    - who is permitted to operate the equipment
    - those who may remain in the controlled area
  - Requirement for:
    - Use of personal dosimeter
    - Wearing and storage of personal protective equipment
  - Practical instructions:
    - Where to stand in the room
    - Significance of warning lights
  - Contingency plans
  - Instructions on contamination monitoring
  - Arrangements for pregnant staff

c) Radiation protection supervisor (day to day responsibility for radiation protection):

- Overall responsibility for radiation protection rests with the employer. However, the employer is required to appoint one or more radiation protection supervisors (RPSs) who are responsible for the day to day management of radiation protection
- Specific responsibilities include:
  - preparation and review of local rules
  - supervision of staff dose monitoring
  - investigation of instances of excessive dose
  - risk assessments (e.g. for pregnant staff)
  - contamination monitoring when radioactive sources are used
  - testing personal protective equipment
  - ensuring that an effective quality assurance programs for X-ray equipment is in place.
  - oversee the work performed to ensure that it is in accordance with dthe local rules.
- Actual performance of RPS duties may be delegated to other staff.
- Employer may establish a radiation protection committee:
  - include representatives of the organization's management and of radiation-using departments, RPAs, RPSs and health and safety advisers.
  - Responsible for radiation protection policies, approval of local rules, and receipt of reports from the RPA.

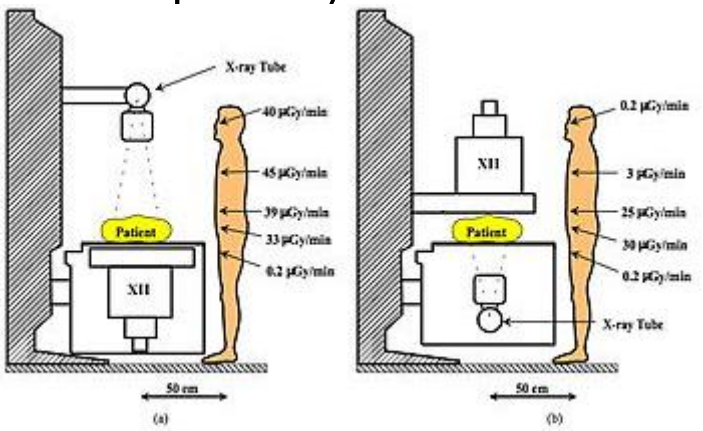
4- Equipment

- Design of radiation equipment should ensure that the risk of exposure to staff and other persons is minimized.
- Equipment examination includes:
  - A) critical examination:
    - Carried out before the equipment is used.
    - Concerned with radiation safety
    - Responsibility for the critical examination rests with the installer.
    - Must be carried out in conjunction with an RPA (not necessarily appointed by the installer, Can be the hospital's own RPA)
    - For X-my equipment, the RPA will check that the equipment complies with the requirements of the **Medical and Dental Guidance Notes**

Medical and Dental Guidance Notes (Sort of ACOP):

- X-ray tube:
  - Tube leakage must be↓ 1mGy/h at distance of 1m. From the focus
  - Total filtration must be ≥ 2.5 mm Al equivalent (1.5 mm for dental equipment operating at ≤ 70 kv)
  - Focus Position should be marked on the tube casing
- Warning signals:
  - There should be an indicator light on the control panel to show that x-ray beam is switched on (visible for shortest exposure times)
- Collimation:
  - Maximum beam size should be restricted to the maximum image size required
  - For fluoroscopy:
    - Collimators should adjust automatically to the FOV with magnification
    - Maximum beam size should be restricted to the area of the image receptor
    - Collimators should be capable of restricting field size to 5x5cm^2

- Exposure switches:
  - Should require positive pressure to be maintained for continuous exposure (except CT)
  - For mobile equipment:
    - exposure switch should be on an extending cable to allow the operator to stand 2m away from the tube (controlled area)
    - Key operated switch to prevent unauthorized use
  - Fluoroscopy foot switches should be designed to prevent inadvertent x-ray production (e.g. fluid entering the switch, pressure on the switch while being stored)
- Shielding:
  - Image intensifier housing shielding of at least 2mm lead equivalent
  - For undercouch fluoroscopy, there should be lead apron suspended from the intensifier support (0.5 mm lead equivalent , 45 cm wide , 40 cm long)
- Fluoroscopy dose rate:
  - Skin entrance dose rate should not exceed 100 mGy/min , action is needed if › 50 mGy/min (for largest FOV and standard sized patient)



- B) Quality assurance programme:
  - Definition:
    - tests to determine whether an equipment is working in accordance with its design specification.
  - Include:
    - commissioning tests before the equipment is first used
    - performance tests at appropriate intervals.
  - Should include:
    - equipment whose performance may affect the patient radiation dose (e.g. AEC, image intensifiers and radionuclide calibrators).
    - periodic assessment of patient Doses.
  - quality assurance programme should ensure that:
    - tests are done in a consistent manner in accordance with a written protocol
    - there are action levels to indicate significant deviation from a baseline value
    - Appropriate action has been taken when action levels have been exceeded
    - a system to ensure that when action levels are exceeded then this is reported to the appropriate manager
    - equipment used for testing is calibrated
    - the process is reviewed at agreed time intervals

N.B. A further critical examination and commissioning test is required following major repair or modification (including software upgrade).

5) Classification of staff and dose monitoring by dosimeters

- Designation of staff as classified persons means that this staff is at particular risk from ionizing radiations (dose is likely to exceed 3/10 of any dose limit).
- To work as a classified person, the individual must be:
  - 18 years old or over,
  - certified as being medically fit to work as a classified person
    - Before employment individual should be seen by an appointed doctor or medical adviser (commonly an occupational health physician whose appointment for this purpose is made by the HSE)
  - subject to dose monitoring and annual health checks
    - the records of these to be kept for 50 years beyond the date that the individual stops working as a classified person.
- Classification is rarely needed for health service personnel (Less than 1% of staff receive more than 1mSv in any year)
- Highest doses tend to be received by:
  - radiographers or technicians working in radionuclide imaging
  - radiopharmacy staff
  - interventional radiologists and Cardiologists.

- The most likely basis for classification is the finger dose especially interventional radiologists and those who prepare radiopharmaceuticals as finger doses may approach 150mSv/year (3/10 the dose limit for the skin).
- IRR99 only makes it mandatory to monitor the dose to classified staff, yet , employer is required to be able to demonstrate that other staff in controlled areas do not require to be classified

i.e. majority of staff working in controlled areas are issued with individual dosimeters

- *Dosimeter must measure the personal dose equivalent (=equivalent dose at a depth of d mm) using different filters:*
  - ***deep dose:*** *(at a depth of 10 mm), is a measure of effective dose,*
  - ***shallow dose*** *is a measure of the skin dose.*

Types of Personal dosimeters:

The standard badge Film:

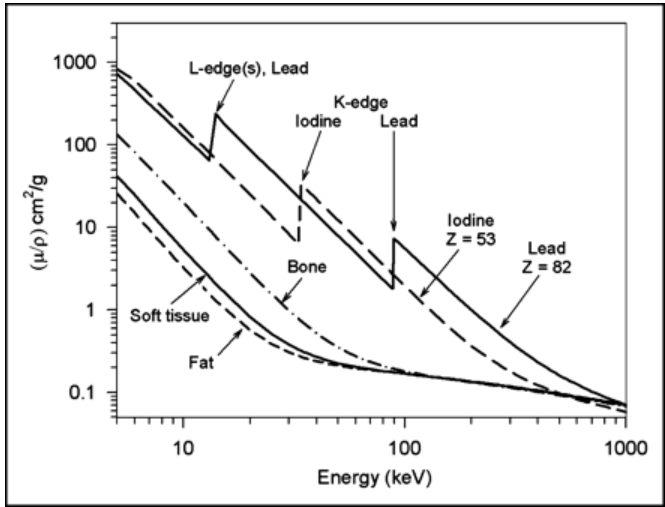
- *Idea:*
  - *Increasing dose results in increasing blackening of the film →provide indicator of dose.*
  - after a specific time period, the film is developed and compared to standards.
- *Advantages:*
  - *Needs simple equipment for processing and reading*
  - Used in conjunction with filters to measure deep and shallow dose
  - Works for high energy betas, gammas, and x-rays.
  - *provides a permanent record of exposure.*
- *Disadvantages:*
  - *Sensitivity of the film (speed) is highly energy-dependent*
  - *Overall sensitivity is no better than 0.1-0.2 mSv.*
  - *Cannot be used for the assessment of finger dose.*
  - *Subject to environmental effects (e.g. heat) → unsuitable for monitoring over periods greater than 1 month.*
  - *Used once only*

- ***Composition:***
  - *The film used for personal dosimeters has different emulsions on each side of the film, with different sensitivities.*
  - *The fast emulsion is used routinely.*
  - *if the badge has received a high dose ,fast emulsion will be too black to provide a meaningful* result →This emulsion is removed and the less sensitive side of the film is used

X-ray film (in light tight packet)

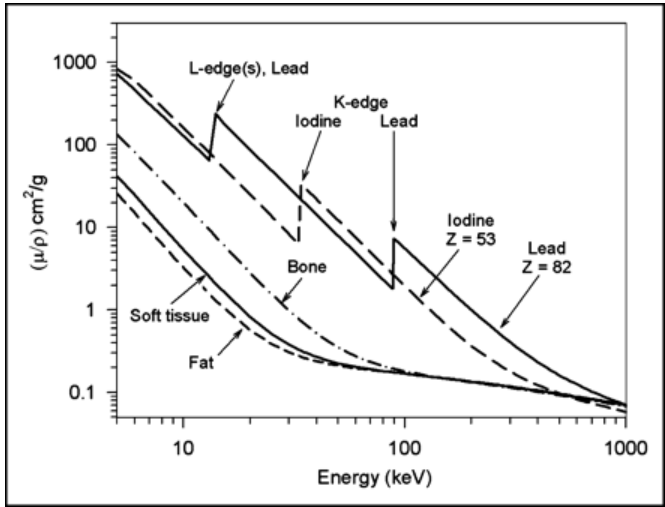
Open window for determining beta exposure

Windows with increasing filters to determine the energies of gammas or x-rays



Thermoluminescent dosimeters (TLDs) :

- **Advantages:**
  - used in conjunction with filters set in the badge holder to measure deep and shallow dose
  - Sensitivity (light output/unit absorbed dose) has minimal energy dependence
  - less susceptible to environmental effects
  - can be reused many times
  - Works for high energy betas, gammas, and x-rays.
- **Disadvantages:**
  - overall sensitivity is not significantly better than film
  - relatively expensive.
  - most common dosimeter to be used for assessment of finger dose.
  - can be read only once.
- **Idea:**
  - See before
- **Material used:**
  - Lithium fluoride ,Z =8.2 (similar to tissues)



Optical simulated luminescent dosimeters:

- **The material used:**
  - Aluminium oxide
- **Idea**:
  - See before (same as ……)
- **Advantage:**
  - increased sensitivity (give readings down to 0.01 mSv)
  - reading process does not fully clear the signal from the phosphor →possibility of a second reading

electronic dosimeters:

- Direct reading devices
- based on Geiger-Muller tubes or silicon diode detectors.
- **Advantages:**
  - Because they provide a direct reading, electronic dosimeters are very useful as a method of dose reduction for procedures in which there is the potential for high doses to staff
  - have a high sensitivity, being able to measure to the nearest 1 µSv.
- **Disadvantages:**
  - expensive.
  - response is highly energy-dependent (but if placed behind suitable filters they can provide reasonably accurate dose measurements)

Notes about dose monitoring:

- Dosimeters should be provided by dosimetry service approved by HSE.
- Dosimetry service should keep dose records (required for classified staff)
- Monitoring period for classified staff = 1 month (3 months for staff receiving lower doses)
- Outside workers:
  - Staff working with more than one employer
  - Required to have a passbook issued by HSE into which doses from each employer is entered

6) Radiation incidents:

- The employer has to notify the HSE in the following incidents:
  - An individual receives a dose greater than any relevant dose limit (including person working with radiation, member of public, fetus of a pregnant worker).
  - A radiation source is spilt, causing significant contamination, or it has been lost or stolen.
    - IRR99 specifies the activities for which notification might be required, e.g. 100MBq for Tc-99m.
  - A patient has received a radiation dose much greater than intended because of an equipment fault (e.g. failure of X-ray exposure to terminate because of a fault in AEC)
    - HSE have provided guidance on what is meant by 'greater than intended', using multiplying factors dependent on examination dose
- the employer must have a system for investigation of all incidents, This would normally involve the RPS and RPA.

Type of diagnostic examination	Guideline multiplying factor applied to intended dose
• Interventional radiology • Radiographic and fluoroscopic procedures involving contrast agents • Nuclear medicine with intended effective dose >5 mSv • CT examinations	1.5
• Mammography • Nuclear medicine with intended effective dose <5 mSv but >0.5 mSv • All other radiographic examinations not referred to elsewhere in this table	10
• Radiography of extremities, skull, dentition, shoulder, chest, elbow and knee • Nuclear medicine with intended effective dose <0.5 mSv	20

7) Personal protective equipment

- One of the functions of the prior risk assessment is to determine what personal protective equipment is appropriate for the particular circumstances.
- 1RR99 place obligation on:
  - employer to provide personal protective equipment.
  - Employer and employee to ensure that personal protective equipment is properly used
- In the case of X-rays, this include:
  - lead aprons
  - thyroid shields
  - leaded glasses or goggles.

IONISING RADIATION (MEDICAL EXPOSURE) REGULATIONS 2000 IRMER

- The emphasis in IRMER: responsibilities of the employer for justification and optimization of individual exposures.

1) Justification and optimization

- IRMER identifies three key persons who have a role in an individual medical exposure.

- *The referrer:*
  - The person who initiates the X-ray request.
  - The employer should
    - define who may act as referrer
    - define restrictions on examinations that may be requested, e.g.
      - » General (medical) practitioners are automatically referrers, but there might be restrictions e.g. may not be permitted to request a CT scan
      - » nurse practitioners may be permitted to request X-rays, in accident and emergency but may be limited to particular examinations e.g. extremities
    - provide the referrer with recommendations on referral criteria e.g. recommendations of the Royal College of Radiologists for this purpose
  - in making the request, the referrer is required to provide sufficient clinical information for the IRMER practitioner to be able to determine whether the examination is justified.

- *The Practitioner*
  - Role: justification of individual exposures, in terms of the clinical benefit set against the radiation risk
  - Training to be an IRMER practitioner requires:
    - theoretical knowledge of radiation protection
    - imaging techniques and experience in clinical practice.
  - Generally, practitioners may be the:
    - Radiologists
    - Radiographers: The extent to which a radiographer may act as an IRMER practitioner depends on the employer, but it is unusual, to have a radiographer who fulfill this role for high-dose examinations (e.g. CT)
    - Dentists: dental radiology is an essential part of their practice and is included in their training.
    - Cardiologists: in respect of cardiac catheterizations:
    - Administration of Radioactive Substances Advisory Committee (ARSAC) certificate holders in respect of radionuclide studies
  - Authorization is the outcome of justification
  - IRMER practitioner may provide justification guidelines to permit the operator to authorize an examination in particular clinical circumstances.

– *Operator*

- The role of the operator is very broad including all practical aspects of the medical exposure that might affect patient dose or image quality, Such as:
  - confirmation of the identity of the patient
  - carrying out the examination
  - processing the image
  - evaluation of the image
  - calibration and maintenance of the equipment
  - preparation and administration of radiopharmaceuticals.
- for a single exposure, there may be several individuals with an operator responsibility.
- IRMER does not require the operator to be a registered healthcare professional, e.g. service engineer.
- IRMER require the operator to be adequately trained for the particular role, e.g. maintenance of the processor . However, minimal training in radiation protection is required for this rule (training need only be concerned with the practical aspects)

- Entitlement to act in any one of these three roles is determined by the employer within certain constraints set in IRMER:
  - both referrer and practitioner must be registered medical or dental practitioners or other healthcare professionals
  - both practitioner and operator must have had training in radiation protection and in the relevant clinical applications of ionizing radiation.

2) Duties of the employer:

- Employer has overall responsibility for compliance with the regulations
- Employers procedures required includes:
  - Patient identification: to ensure that the correct patient is examined or treated
  - Entitlement to act as referrer, practitioner or operator
  - to establish whether the patient might be pregnant or breast feeding
  - Quality assurance programmes
  - assessment of patient dose and administered activity
  - For diagnostic reference levels
  - use of ionizing radiations in medical research programmes, particularly in respect of healthy volunteers
  - Provision of information to patients who have been administered with a radiopharmaceutical, in order to minimize the radiation risks to others
  - evaluation of a medical exposure and recording dose
  - minimize the risk of accidental or unintended exposure of patients

3) Other requirements of IRMER

Diagnostic reference levels (DRL)

- Definition:
  - Doses for typical examinations for standard-sized patients averaged for all rooms in the organization
- Considered as performance standards against which individual patient's dose can be judged (aid to optimization)
- Is set locally by the employer (reflects local practice)
- Should not be greater than national DRL (set by national radiological protection board NRPB) unless it can be justified on clinical ground (use of aging equipment could not be justified)
- DRL should be set in terms of measurable quantities (e.g. DAP for X-ray & CT , activity for radionuclides)
- For large patients DLRs can be exceeded → used to test whether average dose used for particular exam is restricted as far as reasonably practical (not on individual basis)

Exposures not for direct health benefits:

- examples:
  - medico-legal exposures
  - research programs
  - Screening for healthy individuals
- For researches there must be:
  - Approval from appropriate research ethics committee
  - Participation is voluntary
  - Participants are informed about the risks of exposure
  - Dose constraints

Special attention areas:

- Children
- High dose procedures
- Breast feeding (radionuclide exams)
- Examination of female patients in reproductive age **(12-55):**
  - Consideration has to be given to possibility of pregnancy when imaging **abdomen & pelvis** (examination may not be justified due to risk on the fetus)
  - Two approaches are available:
    - The 10 day rule:
      - establish date of LMP & schedule the exam to be no more than 10 days from this date
      - Unnecessarily restrictive (doesn't consider patient's personal circumstances)
    - The 28 day rule:
      - Ask the patient whether she is or might be pregnant
        - » If she rules out pregnancy possibility→ proceed with the examination
        - » If not→ IRMER practitioner should reconsider the justification
      - More commonly used (except sometimes in high dose examinations e.g. CT)

Quality assurance

- quality assurance requirements of IRMER are concerned with procedures and doses.

Medical physics expert

- The employer is required to ensure that a medical physics expert (MPE) is involved with medical exposures.
- This involvement is likely to be with optimization including patient dosimetry and quality assurance.
- The role of the MPE and RPA are usually closely linked.

Inventory

- employer should keep an inventory of equipment used for medical exposures.

Notification and enforcement

- There is a requirement to notify the appropriate authority if the dose to the patient is much greater than intended.
- This does not include incidents involving equipment faults for which notification to HSE is required under IRR99 (see before).
- Notifiable incidents include for example those in which the wrong patient was examined
- in England and Wales, the enforcement authority is the Healthcare Commission.

Radioactive Substances Act 1993

- In contrast to IRR99, which is concerned with the protection of individuals, the Radioactive Substances Act 1993 is concerned with the protection of the population as a whole and the protection of the environment.
- Concerned about:
  - licensing users of radionuclide to hold radioactive sources
  - Authorization for their disposal through licensed disposal routes.
- Hospitals are regularly inspected by the enforcing authorities (the Environment Agency in England and Wales) to ensure compliance with the conditions for registration and authorization

Medicines (Administration of Radioactive Substances) Regulations 1978 (MARS)

- concerned with the protection of the patient (like IRMER) .
- For doctors to be able to administer a radioactive product to a patient, they must have been granted a certificate licensing them for that particular procedure
- The certificate will only be issued on the basis of evidence that the applicant has received adequate training and has sufficient experience.
- The license is specific to the hospital issued only if there are adequate facilities.
- Certificates are granted by the Administration of Radioactive Substances Advisory Committee {ARSAC),
- ARSAC issues guidance on approved tests and normal and maximum levels of activity to be used (national DRLs for these procedures)

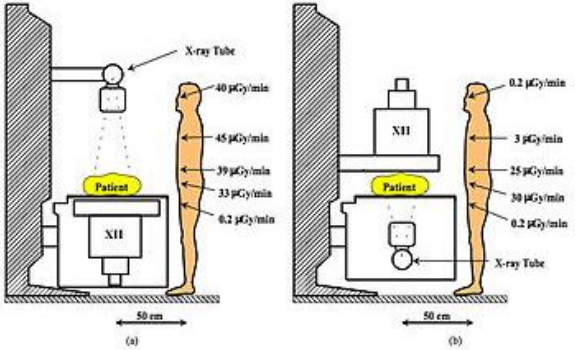
PRACTICAL ASPECTS OF RADIATION PROTECTION

1) Protection of staff

Room design

- The most effective form of protection of staff is to exclude them from the controlled area (can not be applied to all staff)
- X-ray rooms are designed so that the radiation doses in adjacent areas are sufficiently low for staff in those areas to receive doses no greater than the public dose limit (dose constraint of 0.3mSv)
- account may be taken of occupancy of the adjacent area (e.g. less shielding is required for a storage area than for an office).
- Protection is achieved through wall shielding
- sufficient shielding is achieved with use of 1-2 mm of lead.
  - In a modern construction, with timber frame partition walls (stud partition), lead is incorporated using plaster- board on to which lead sheet has been bonded.
  - In older buildings, there may be brick or concrete block internal walls with sufficient shielding properties (single thickness of solid brick provide protection equivalent to 1 mm of lead)
  - alternative protection material is barium plaster, which exploits the photoelectric effect by substituting barium (↑Z) for calcium
  - Doors to x-ray rooms should also incorporate lead
  - Within the room 2mm lead screens (viewing windows) is used

Radiation sources:



- Primary beam:
  - Must be Collimated to the region being examined
  - In fluoroscopy must be:
    - Not greater than size of image receptor
    - Not more than 10% larger than FOV on the monitor
  - Could expose operator fingers→ protective gloves should be worn
  - Undercouch tube is preferable in terms of staff dose
- Transmitted radiation:
  - At the exit side of the patient
  - Less than 2% of the primary beam
  - In fluoroscopy, transmitted radiation at back of the image intensifier is negligible
- Leakage radiation from the tube:
  - Must be less than ……
- Scatter radiation:
  - Compton interaction with the patient (& collimator)
  - Main radiation source to which staff are likely to be exposed
  - Amount of scatter depends on
    - α Amount of 1ry radiation
    - α Area of the patient irradiated (i.e. scatter α DAP)
    - α Kv
    - Scattering angle (scatter towards X-ray tube is ↑by factor of 2, at exit side of the patient is halved)
  - Maximum scatter amount at distance of 1m from the patient = 5µGy/(Gy.cm²)

Protection in practice:

- Distance (inverse square law) must be used
- Exposure time must be reduced
- Undercouch tubes is better because maximum scatter dose will be to the lower part of the body (less radiosensitive)
- Overcouch tubes:
  - Should only be used with protective screens
  - Not suitable for interventional procedures
- In oblique views: x-ray tube should be angled away from operator (why?)

- Protective clothing:
  - Lead apron:
    - types:
      - 0.25 mm → transmit 5%
      - 0.35 mm → transmit 3%
      - 0.5 mm → transmit 1.5%
    - Thickness used depends on the local risk
      - 0.35 mm for general work
      - 0.5 mm for interventional procedures
    - Weight can be reduced by:
      - having thinner lead in the back
      - Use of lightweight materials (↓ Z materials as barium and tin , with suitable k-edge for energies below lead k-edge) → 30% weight reduction with the same protection
  - Thyroid collar:
    - 0.5 mm lead equivalent
    - Should be used for high dose procedures
  - Lead glasses
    - For interventional radiologists
    - Must provide protection on the sides
    - No need to be used when using lead glass panel
  - Lead gloves
    - For interventional radiologists
    - 0.25 mm lead

2) Protection of the patient:

- Most important factor: ensure that images have sufficient quality with no need for repeating
- Collimation: visualization of collimator edges confirms that there are no unnecessarily exposed area of the patient
- In fluoroscopy:
  - the use of magnified FOV may ↓ dose (why?), but not as great as the reduction produced by coning down the required FOV
  - Image intensifier should be as close as possible to the patient
  - Removal of grids during examination of young children (loss of image quality in adults may lead to increased screening times)
- Supplementary shielding of sensitive structures within the FOV (shielding gonads of a child during x-ray hip), provided that inaccurate shield positioning will result in repeating of X-ray
- Some systems is provided with additional filters (copper) that can be driven into place

3) Patient dose assessment:

Effective dose:

- Examinations are divided into three groups:
  - High dose:
    - ≥2mSv
    - i.e. comparable to the average annual dose from natural background radiation
    - Moderate risk (1 in 10000)
    - Includes CT abdomen and pelvis (10mSv) , CT chest (8mSv), barium enema (7mSv), Tc bone scan (5mSv), IVP (3mSv) , barium meal (2.5mSv) , CT head (2mSv)
    - Also include fluoroscopy with screening time ≥ 1min
  - Medium dose
    - 0.2-2 mSv
    - i.e. comparable to the annual dose limit for public members
    - Low risk
    - includes barium swallow (1.5mSv) , Tc lung perfusion study (1 mSv) , x-ray lumber spine (0.8mSv) , AP pelvis (0.6mSv) , x-ray head (0.04mSv)
  - Low dose:
    - ≤0.02mSv
    - Comparable with average daily dose from natural background radiation
    - Trivial risk
    - 60% of medical exams , e.g. chest AP (0.015mSv), shoulder AP (0.005mSv) , dental (0.004 mSv) , extremities (0.0001-0.005 mSv)

Entrance skin dose (ESD):

a) Measurement using TLD:

- disc with 4mm diameter
- 1mm thickness (thin enough to be non visible in the radiograph)
- Placed on the entrance surface
- After examination placed in a reader (uncertainty = ±5%)

b) calculation:

- Kv & mAs are used to calculate air kerma
- Air kerma at skin position is calculated using inverse square law correction
- Further correction to account for the scatter from the patient = back scatter factor = 1.25-1.5
- Accuracy of calculation is dependant on skin to focus distance (not recorded)

- Use of ESD is restricted to single projections (not applied to multiple projections)

Dose area product (DAP)

- Described before
- Standard specification for fluoroscopy
- Most common quantity to use for patient dose audit

N.B. Patient dose audit is imprecise quality assurance tool (required by IRR99) due to patient to patient variations (dose vary by factor of 10)

Effective dose and DAP

- DAP is not direction indication to patient risk
- It is possible to convert DAP value to effective dose using theoretically derived conversion factors depending on:
  - Body region
    - Conversion factor for skull & shoulder is less than trunk
  - Projection
    - Conversion factor for PA examinations is less than fot AP examinations
  - Kv & filtration (to lesser extent)

N.B:

- Variations in conversion factors for trunk examinations are small (tissues with high weighting factors are evenly distributed)
- Conversion factors used in barium studies are more variable (small FOV are used)
- Validity of this factors are dependant on size of x-ray beam

End of physics